MODELING GROWTH STAGE OF TWO SPRING WHEAT CULTIVARS - NEEPAWA AND HY320: I. PHENOLOGICAL DEVELOPMENT CHARACTERISTICS

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INTRODUCTION

Simulation of phenological development is an essential component of any crop modeling exercise. Most phenological development models are empirical, based on degree day (thermal time) relationships. Under a given set of environmental conditions, the degree days accumulated during a given growth phase is assumed to be a constant which is cultivar dependent. These thermal constants are sometimes included in a group of growth characteristics referred to as genetic constants, which are specific to a given cultivar.

Studies have been carried out at Swift Current to compare growth characteristics of Neepawa and HY320 spring wheats in response to varying environmental conditions. This paper will report on the similarities and differences in the phenological development-thermal time relationships between Neepawa and HY320 when grown under irrigated and dryland conditions. Genetic constants determined from these studies are being used to modify and adapt Ritchie's 'CERES' wheat growth model for use in the Brown soil zone.

MATERIALS AND METHODS

A. Wheat growth analysis study - 1984, 1985, 1986

Experiment 1 — Partial irrigation - 1984: Neepawa and HY320 were grown on summerfallow in a randomized complete block with 6 replications at Swift Current. The plots were seeded May 9 and fertilized with 65 kg N/ha 46 kg P_2O_5/ha broadcast and incorporated just prior to seeding. A total of 145 mm of irrigation water was applied in 5 irrigations (25.4 mm May 12, and the rest between July 9-23) using sprinklers.

Throughout the plot area, main culms of several plants were randomly chosen to determine the date of occurrance of the growth stages - emergence, ligule of last leaf visible (LLV), anthesis, maturity (ripe) - as defined by Robertson (1968).

At anthesis the heads of 100 similar main culms in each plot were tagged and from 5 days after anthesis until maturity, 5 heads per cultivar per plot were sampled every 2 to 4 days. The kernels from the central spikelets were removed, counted, dried and weighed. For each cultivar, the relationship between kernel weight and accumulated growing degree days after anthesis was described by the logistic equation:

$$W=Wf/(1+B*EXP(-K*GDD)) \quad (1)$$

where W is the kernel dry weight (mg), Wf is the final (potential) kernel weight, K is a constant, GDD are the growing degree days accumulated from anthesis and B=(Wf-Wo)/Wo where Wo is the initial kernel weight at anthesis. Growing degree days were calculated using the equation:

$$GDD=((Tmax+Tmin)/2)-Tb \qquad (2)$$

where Tb is the base temperature, and Tmax and Tmin are the daily maximum and minimum temperatures, respectively.

With Tb = 0 C, the relationship of kernel weight to GDD was determined for each of the irrigation experiments, 1 (1984) and 2 (1985). The relationship between kernel weight and GDD was also determined for the pooled data of experiments 1 and 2. GDD's were calculated with the Tb that resulted in the lowest SS error when the logistic equation was iteratively fit to the pooled data.

All GDD in this paper are calculated using air temperatures.

Soil samples were taken at seeding, anthesis and maturity for gravimetric moisture determination to 120 cm.

Experiment 2 — Full irrigation - 1985: In 1985 the experiment was repeated under optimum moisture and fertility conditions. All plots were seeded May 7 and fertilized with 116 kg N/ha and 58 kg P_2O_5/ha broadcast and incorporated just prior to seeding. A further 58 kg N/ha and 29 kg P_2O_5/ha were broadcast at about the 3 leaf stage.

Ritchie's 'CERES' model was used to estimate irrigation requirements. Water was added to bring the soil to field capacity whenever the rooting depth soil moisture content reached 50 % of the available water capacity.

Development stages and moisture use were determined as in experiment 1.

Experiment 3 — Dryland - 1985: This experiment was similar to experiment 2 except there were no irrigations. Fertilizer N and P was applied at recommended dryland rates.

Experiment 4 — Dryland - 1986: The plots were seeded May 27 (late seeding due to inclement weather) on summerfallow with no irrigations. Fertilizer N and P_2O_5 were applied at rates of 60 kg/ha and 30 kg/ha, respectively. Determination of kernel development rate after anthesis was omitted.

B. Drought physiology study - 1986

This study was situated approximately 200 m from experiment 4 and consisted of plots grown under dryland and full irrigation. Fertilizer N and P were added at rates recommended for dryland and irrigation, respectively. These plots were seeded May 17. The dates of anthesis and maturity (ripe) were determined for both dryland and irrigation.

C. Moisture stress-crop response study - 1987

Neepawa and HY320 were grown under 4 moisture regimes: 3 irrigation treatments designated 60 % AVM (available moisture - referred to as full irrigation), 40 % AVM, 20 % AVM; and a dryland treatment. The plots were seeded May 11. Fertilizer was broadcast and incorporated just prior to seeding at rates of approximately 180, 150, 120, 60 kg N/ha and 80, 60, 60, 40 kg P_2O_5/ha for the 60, 40, 20 % AVW and dryland treatments, respectively. Under each moisture regime, the cultivars were grown in a completely randomized design with 4 reps per cultivar. From each rep, 4 plants were randomly chosen and tagged (for a total of 16 plants/cultivar in each moisture regime) to determine the dates on which the following growth stages occurred - emergence, LLV, heading, anthesis, ripe; and to determine maximum leaf number and leaf appearance rates (using the Haun scale - Klepper et al. 1982). These observations were recorded for the main culm of each plant. The beginning of leaf emergence occurred when the tip of the emerging leaf just extended above the ligules of the preceeding leaf, and the leaf was fully emerged with the appearance of the ligules.

The 4 moisture treatments were determined on the basis of percentage available water used from the rooting depth. Water use was monitored with Ritchie's 'CERES' wheat growth model. As a check, soil moisture content to 120 cm was also measured every two weeks with a neutron probe. For the 60 % AVW treatment, irrigation water was added when 40 % of the available water in the rooting depth was used, i.e., the rooting depth profile was not allowed to dry below 60 % AVW. Similarily, for the 40 and 20 % AVW treatments, the rooting depth was not allowed to dry below 40 and 20 % AVW, respectively, before filling the profile to field capacity.

RESULTS AND DISCUSSION

Rate of Development of Plant

HY320 matured approximately 4 to 5 days later than Neepawa, with the delay in maturity ranging from 0 to 8 days (Table 1). When comparing cultivars, the delay in maturity was relatively independent of moisture regime. However, within a given year, irrigation substantially delayed maturity; the response to irrigation was similar for both cultivars (Table 2). Irrigation delayed maturity approximately 29 days in 1985 (a drought year - May,June,-July rainfall = 73 mm) and approximately 16 days in 1986 (a 'wet' year - M,J,J rainfall = 205 mm). Both cultivars were most sensitive to improved moisture conditions after anthesis (Table 2). With irrigation, the duration from seeding to anthesis was increased 5 to 7 days in 1985 and 2 to 3 days in 1986, whereas the duration from anthesis to maturity was increased 23 days in 1985 and 12 to 15 days in 1986.

The duration from seeding to anthesis was 3 to 6 days longer for HY320 than Neepawa, with a tendency for the difference to be greater with improved moisture conditions (Table 2). However, differences in the duration from anthesis to maturity ranged from -2 to 3 days. This data (and data from other experiments) suggest that the duration from seeding to anthesis was always longer for HY320. The same tendency occurred for duration from anthesis to maturity when conditions were wet and cool, but when dry and hot, the converse was true.

Table 1. Duration (days) and growing degree days (GDD - above 0 C) from seeding to maturity with varying water use (WU).

Cultivar	1985 dryland WU=164 mm	1986 dryland WU=287 mm	1984 partial irrigation WU=374 mm	1985 full irrigation WU=547 mm	
a) days					
HY320	97	94	105	127	
Neepawa	91	91	105	119	average difference 4.3 days
difference	6	3	0	8	
b) GDD (C-day)					
HY320	1548	1656	1787	1955	
Neepawa	1461	1594	1787	1885	average difference 55 C-days
difference	87	62	0	70	

Table 2. Duration (days) from seeding to anthesis, anthesis to maturity, and seeding to maturity for HY320 and Neepawa under irrigation and dryland in 1985 and 1986.

Growth interval	Neepawa Irrigation	Neepawa Dryland	Neepawa Difference	HY320 Irrigation	HY320 Dryland	HY320 Difference
a) 1985						
seeding to anthesis	65	60	5	70	63	7
anthesis to maturity	54	31	23	57	34	23
seeding to maturity	119	91	28	127	97	30
b) 1986						
seeding to anthesis	56	54	2	62	59	3
anthesis to maturity	50	35	15	48	36	12
seeding to maturity	106	89	17	110	95	15

The thermal time (GDD accumulated using air temperatures, Tb = 0 C) from seeding to maturity was generally greater for HY320 compared to Neepawa (Table 1). GDD also increased with increased water use. In 1985, GDD to maturity were approximately 400 C-days greater for irrigation compared to dryland.

The above observations indicate that there are cultivar differences in the thermal time required to complete a given stage. However, these thermal times (genetic constants), when estimated from air temperatures, are dependent upon water availability (water use), i.e., the thermal time required for a given growth phase increases with improved moisture conditions.

Rate of Leaf Development - Seeding to Anthesis

The differences between HY320 and Neepawa in the duration of this growth phase occur after emergence.

Contributing to the differences between cultivars in the duration from emergence to anthesis is the number of leaves produced by the main stem of each cultivar. HY320 produces 2 more leaves on the main culm than Neepawa (Table 3). The detailed plant observations of the moisture stress-crop response study in 1987 showed that Neepawa produced a total of 7 or 8 leaves on the main culm while HY320 produced 9 or 10 leaves. For every plant that produced the higher leaf number, there were 3 plants that had the lower leaf number. This 3:1 ratio was observed for both cultivars and was relatively independent of moisture regime.

Under both irrigation and dryland, there was a highly significant linear relationship between accumulated GDD above 0 C and the leaf stage determined using the Haun scale (Table 4). The slope of the regression, called the phyllochron interval (PI), is the thermal time interval between appearance of successive leaves (Baker et al. 1986). The reciprocal of PI is the leaf appearance rate (leaves/thermal unit). Thus, increasing PI is equivalent to decreasing leaf emergence rates. For both irrigation and dryland, PI was greater (leaf appearance rates lower) for Neepawa than for HY320. PI was also greater under irrigation than dryland, indicating that when GDD are calculated using air temperatures PI is dependent upon moisture conditions, i.e., for a given cultivar, leaves appear faster under dryland compared to irrigation. Although leaves appear faster for HY320, the increased rates do not completely compensate for the increased leaf number, resulting in delayed anthesis.

For individual plants, the linear curves of GDD (accumulated from seeding) versus leaf stage are parallel indicating equal PI (Figure 1). The curves are separated because of differing plant emergence dates. These results suggest that, under a given moisture regime, PI (and leaf appearance rate) is a genetic characteristic with little plant to plant variability.

Rate of Grain Development - Anthesis to Ripe

Logistic equations were used to describe the relationship between the

Table 3. Number of plants, out of 16 (only 15 Neepawa plants in the 40 % AVW treatment), producing the corresponding number of leaves on the main stem for HY320 and Neepawa grown under varying moisture regimes.

Moisture regime	Number of leaves on main stem Neepawa		HY320	
	7	8	9	10
60 % AVW[+]	13	3	11	5
40 % AVW	9	6	14	2
20 % AVW	12	4	10	6
dryland	12	4	11	5
average	12	4	12	4

[+] AVW - available water

Table 4. Linear regression equations relating accumulated growing degree days (GDD - above 0 C) to leaf stage (LS - >= 3 to 4 leaf stage) for irrigated and dryland conditions in 1987.

Cultivar	Equation	R**2[+]
a) irrigation		
HY320	GDD = 71.8 LS + 21.7	0.890
Neepawa	GDD = 89.7 LS - 8.7	0.862
b) dryland		
HY320	GDD = 68.4 LS + 32.0	0.906
Neepawa	GDD = 85.5 LS - 49.9	0.885

[+] all equations highly significant (P<0.001) increase in weight of the kernels taken from the central spikelets of the main culm versus GDD accumulated (above a base temperature of 0 C) from anthesis (Figure 2). The ripe stage was defined as having occurred when kernel weights were 95 % of their potential (0.95 Wf). The duration in days from anthesis to ripe was approximately 33 and 43 days for the 1984 and 1985 irrigation experiments, respectively; a difference of 10 days (Table 5). However, in relative terms, GDD were only slightly greater in 1985 compared to 1984; the difference was consistent with cultivar. The average GDD was greater for HY320, indicating that under irrigation, HY320 required slightly more thermal time to complete grain filling than did Neepawa. However, in the drought year of 1985, HY320 required slightly less thermal time than Neepawa to complete grain filling. Also, in 1985, the thermal time (and duration in days) to complete grain filling was substantially less for dryland compared to irrigation. Therefore, the thermal time (accumulated air temperatures) to complete grain filling was dependent upon moisture availability - GDD increased as moisture conditions improved.

When logistic equations were fitted to the pooled data of the 1984 and 1985 irrigation experiments, the result was a more accurate estimation of the thermal time to complete grain filling under irrigation (Figure 3 and Table 6). With this fitting procedure ,base temperatures (Tb) for grain filling were 7 and 9 C for Neepawa and HY320, respectively.

SUMMARY

1. HY320 matured approximately 4 to 5 days later than Neepawa. The delay in maturity was independent of moisture regime. Relative to dryland, irrigation delayed maturity 15 to 30 days. The cultivars were most sensitive to improved moisture conditions after anthesis.

2. HY320 produces 2 more leaves on the main culm than does Neepawa. Leaf appearance rates were greater for HY320. However, the increased rates did not completely compensate for the increased leaf number, contributing to the delayed anthesis of HY320 relative to Neepawa.

3. Fitting logistic equations to the pooled irrigation grain development data indicated that Tb (the base temperature for grain development) > 0 C; Tb = 7 and 9 C for Neepawa and HY320, respectively. The thermal time (GDD) for grain filling was more accurately estimated from the pooled data than from the data for individual years.

4. When comparing irrigation and dryland in the same year, thermal times to complete any given growth phase were lower under dryland, i.e., the effect of thermal units were a function of moisture availability. Thermal units were accumulated using air temperatures, but plant development rates are a function of plant temperature. Plant temperature is a function of the heat load placed upon the plant (i.e., air temperature, solar radiation) and the dissipation of heat from the plant (i.e., moisture availability, wind). Moisture availability may not directly influence development rate, but through evaporative cooling, moisture indirectly alters development by lowering plant temperature. Therefore, by accumulating plant temperatures, thermal times for a given stage should be relatively independent of moisture conditions, i.e., thermal times defined by plant temperature would be constants independent of moisture regime.

Table 5. Duration (days) and GDD (C-days) above 0 C from anthesis to 0.95 Wf for Neepawa and HY320 in the irrigation experiments of 1984 and 1985, and in the 1985 dryland experiment.

Year	Irrigation				Dryland			
	Neepawa		HY320		Neepawa		HY320	
	GDD	days	GDD	days	GDD	days	GDD	days
1984	678	32	705	33				
1985	768	41	777	44	536	28	509	27
average	723		741					

Table 6. Coefficients (Wf, B, K) of the logictic equations, base temperatures (Tb), and GDD (C-day) above Tb from anthesis to 0.95 Wf. Wf is the potential kernel weight.

Cultivar	Coefficients			Tb (C)	GDD from anthesis to 0.95 Wf (C-day)
	Wf (mg)	B	K 1/(C-day)		
Neepawa	38.2	39.2	0.0141	7	469
HY320	45.5	25.0	0.0155	9	398

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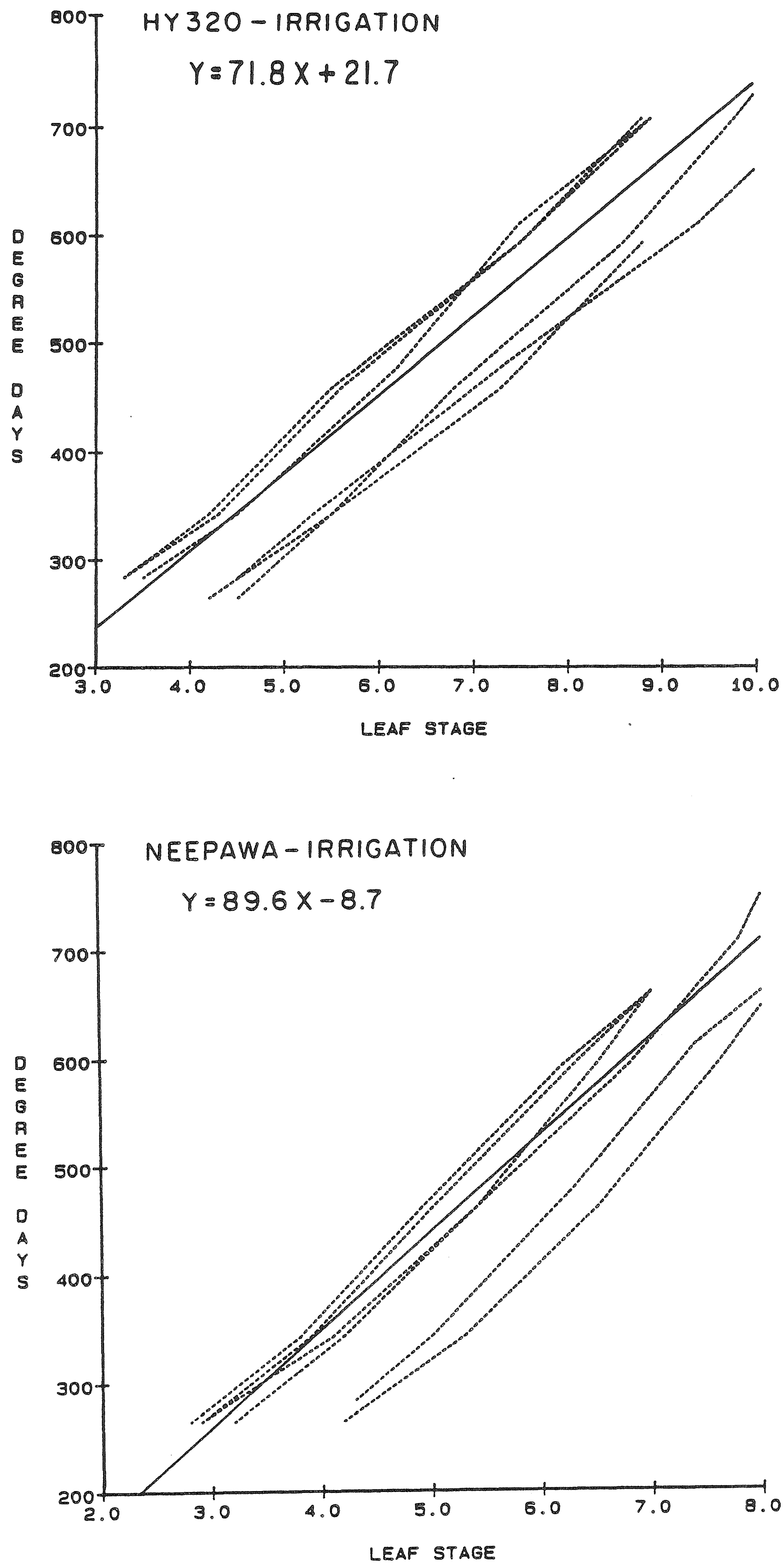
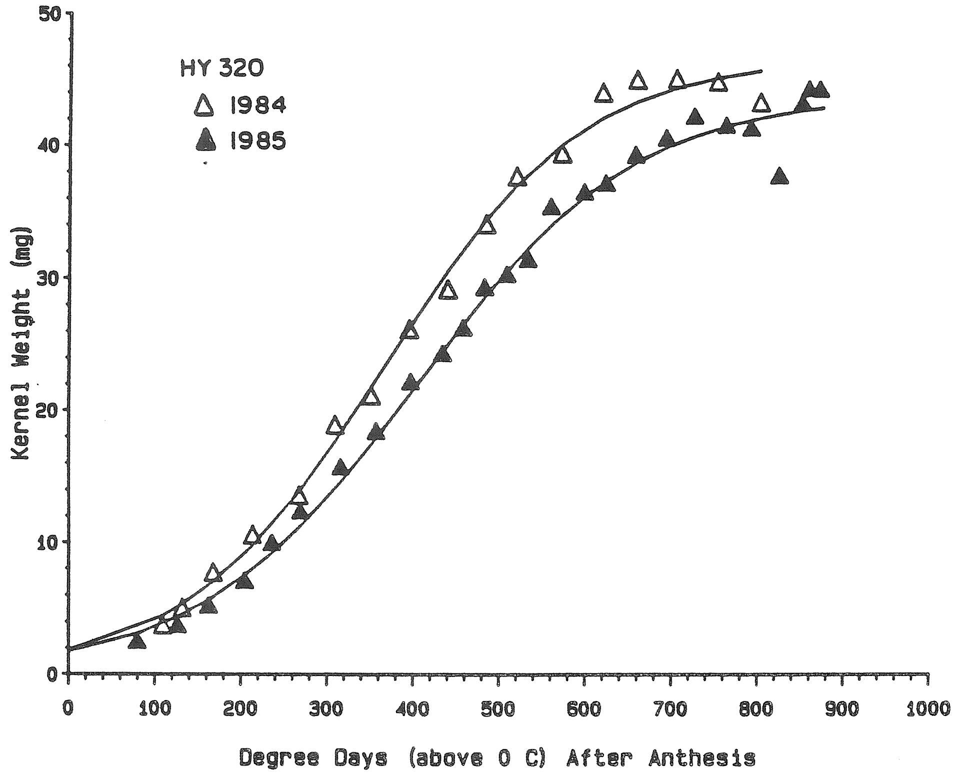


Figure 1. Accumulated growing degree days (above 0 C) from seeding date versus leaf stage for HY320 (top) and Neepawa (bottom) grown under irrigation in 1987. (Dashed lines - actual data for individual plants; solid line - predicted values from regression analysis)



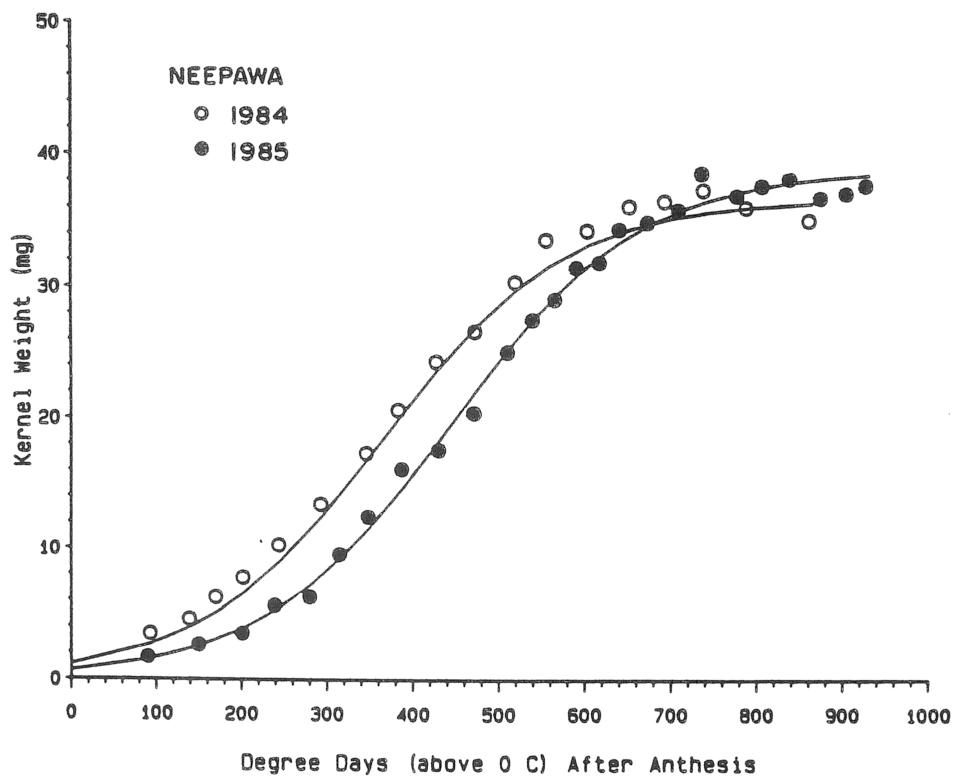


Figure 2. Relationship between kernel weight and degree days above 0 C from anthesis, for HY320 (top) and Neepawa (bottom) grown under partial irrigation (1984) and full irrigation (1985).

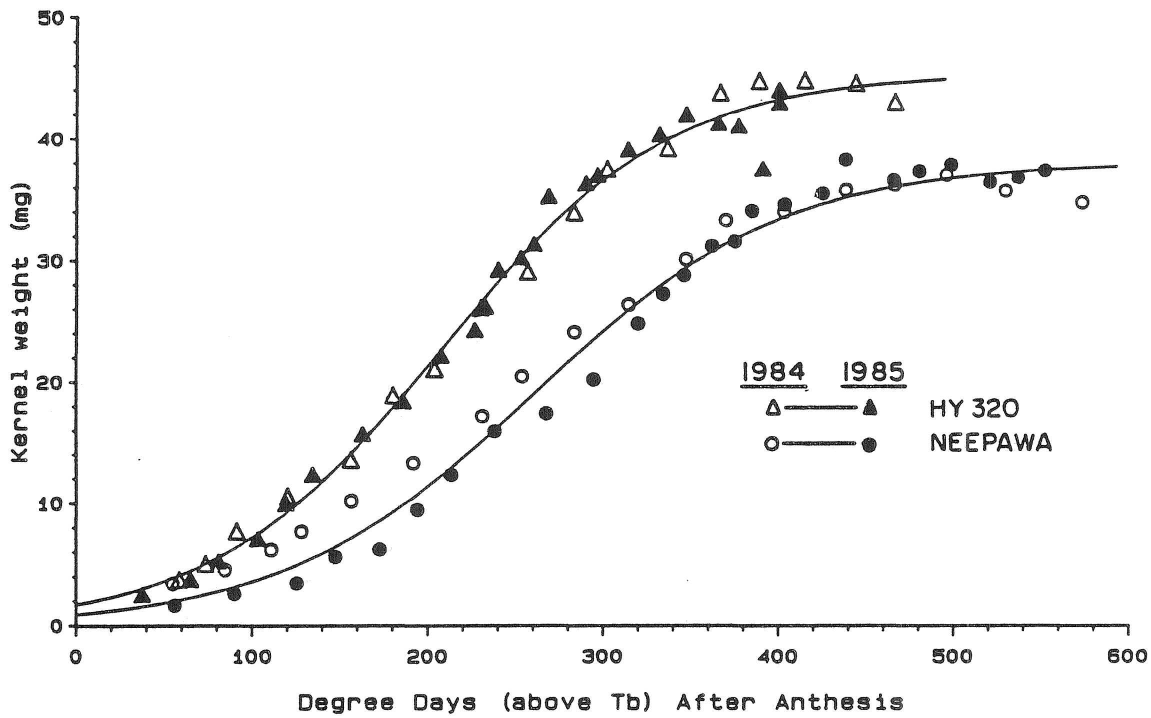


Figure 3. Relationship between kernel weight and degree days above Tb from anthesis, for HY320 and Neepawa grown under partial irrigation (1984) and full irrigation (1985).